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REMOTE MONITORING OF ROCK WEDGE AT ABITIBI CANYON GS

Report No. 91-79-K

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ABSTRACT

A remote monitoring system was set up to monitor the potential movement and tilt of a large rock wedge on the tailrace slope at Abitibi Canyon GS. This system allows continuous monitoring so that remedial measures can be instigated at an early stage if required.

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REMOTE MONITORING OF ROCK WEDGE AT ABITIBI CANYON GS

1.0 INTRODUCTION

A remote monitoring system has been installed by the Rock Sciences Section (Civil Research Department) at Abitibi Canyon GS to monitor a rock block on the east tailrace wall. The recommendation to monitor this rock block was presented in Research Division Report No 89-431-K entitled "Assessment of Rock Slope Stability - Abitibi Canyon GS".

The report also provides details on the location and condition of the rock wedge which is separated on each side by a fault.

2.0 DRILLING OF BOREHOLES

Three diamond drill boreholes were drilled into the rock block to enable the installation of extensometers and inclinometers (Figure 1). Prior to the drilling operation, a zone next to the drilling location had to be cleared of trees to enable a helicopter to load and unload the equipment. The clearing of the helicopter pad was organized and supervised by the regional staff.

After the trees were cleared, a wooden drill platform was constructed. The diamond drill was dismantled to make helicopter loads lighter. All of the equipment was then flown across the Abitibi River to the drill site. At the drill site the diamond drill was reassembled.

Drilling of the first hole commenced on August 22, 1989. This hole was a vertical hole to accommodate inclinometers and was drilled to a depth of 66 feet at which point drill advancement was very slow. The hole was abandoned and another borehole was drilled to a depth of 100 feet. It was decided that the shallow hole would be used for the upper inclinometer while the deeper hole would be used for the lower inclinometer.

A third borehole was drilled at an angle of 60° degrees from horizontal to a depth of 66 feet. This borehole was drilled to enable the installation of a three point extensometer. The drill logs for all three boreholes are provided in Appendix A.

Subsequent to the completion of the drilling program, the diamond drill was once more dismantled. All of the equipment was then taken out by a helicopter.

3.0 EXTENSOMETER

The remote monitoring system (Figure 2) consists of the following major components: 1) extensometer, 2) inclinometers with relay switch, 3) solar panel, regulator and batteries, 4) data logger, 5) storage module for data backup, 6) RF modems, UHF transceivers and antennas, 7) telephone modems and telephone lines and 8) computer and peripherals.

3.1 Extensometer

The Model A-6 Extensometer uses continuous lengths of fibreglass rods (inside protective PVC tubing), which are cut to customer-specified lengths, coiled at the factory and shipped ready for installation. The extensometer is lightweight, which makes it easier to handle during installation and less costly to ship. Furthermore, on-site assembly time is minimized and the installation procedure is greatly simplified. All of these parameters make this extensometer an excellent candidate for installations where access is difficult. Hydraulic anchors with oil-filled pressure lines were used at each anchor point in the borehole. To permit the readout of the extensometer rods, a linear potentiometer was used. These units feature a rugged waterproof design that permits remote and/or

continuous electronic readout and also allows a mechanical check on the readings using a dial gauge or a depth micrometer. Each sensing point has a movement range of four inches, a linearity of 0.1%, an accuracy of 0.5% and a resolution of 0.001 inches.

3.2 Inclinometers and Relay Switch

The Schaevitz LSRP-14.5° inclinometer is fully self-contained and designed to operate from a standard DC power source. Its output is an analog DC signal directly proportional to the size of the angle of tilt. In a level (horizontal) position, the DC output is zero. When tilted in one direction, the inclinometer output is 0 to +5V DC full scale. When tilted in the opposite direction, the output is 0 to -5V DC full scale. The heart of this closed loop, gravity-referenced sensor is a flexure-supported torque-balance system, rugged enough to withstand severe shock and vibration and still maintain excellent accuracy. The solid-state electronics and sensor are enclosed within the sealed housing, permitting operation in hostile environments.

In an effort to minimize energy drainage of the batteries, especially in the cold winter months, relay switches can effectively be utilized. The SWC/SW12 Switch Closure/Switched +12 Volt Relay Driver provides the user with either a switch closure or a switched +12 volt excitation. If a sensor requires a voltage other than 12 volts, an external battery or power supply can be used with the switch closure mode to open and close the circuit.

3.3 Solar Panel Regulator and Batteries

The Model SX10 Solar panel is a photovoltaic power source, which is used with Campbell Scientific dataloggers equipped with rechargeable lead-acid batteries. The voltage output from the panel is unregulated and is intended to be used as an input to a battery float charger circuit. The specifications of the solar panel are as follows: Peak power: 7 watts; Voltage at peak power: 15.2 volts; Watt-hours per week: 180 and Ampere-hours per week at 15.2 volts: 11.8. These are typical panel characteristics at 1 kilowatt per square metre illumination and 25 °C. Individual panels may vary up to 10 %. The panel voltage output increases slightly as the panel temperature decreases.

The purpose of the PS35 12- and 5-volt Charging Regulator is to provide a temperature compensated, current limited charging voltage for 12-volt lead acid batteries. In addition, the PS35 provides a regulated 5-volt power supply for datalogger peripherals and sensors

while connected to a 12-volt battery. The PS35 accepts an input voltage from an SX10 solar panel. The SX10 is supplied with the appropriate connector for direct connection to the PS35.

3.4 Data Logger

The Campbell Scientific 21X data logger is responsible for collecting, saving and transmitting data in response to the control program which is entered by the user. The 21X design is a modular approach, combining precision measurement (14 bit) with processing and control capability into a single battery operated system. The control module includes a 16-pad keyboard and 8 digit LCD display. The programs are entered by the user via this keyboard or downloaded from a computer, which instruct the control module to initiate measurements or control functions, process data acquired from the I/O module and store data in final storage. The data logger is also used to power 5-volt instruments, such as the potentiometers for the extensometers.

3.5 Data Backup

The SM 192 Storage Module provides data backup for the Campbell Scientific data logger. Data is stored in RAM memory and backup power is provided by an internal lithium battery. The advantage of this storage device is that it can operate down to -40°C while the operation of the traditional cassette recorder becomes questionable below 0°C.

3.6 R.F. Modems, UHF Transceivers and Antennas

The function of the Model DC95 RF Modem is to establish an RF Link between a Land Modem and a Campbell Scientific datalogger. The DC95 connects to a radio transceiver (HT90) which transmits and receives the modulated RF carrier. This modulated carrier is used to transmit the information required to transfer data and commands. The average line of site range is 20 - 25 miles.

The RF modem is powered by the 5 volts supplied by the PS35 charging regulator. When the DC95 is active it typically requires 19mA, when inactive it requires 100 - 200 microamps. At the field station (north side of Abitibi River), the RF modem is located between the 21X data logger and the VHF transceiver. At the base station (pumphouse south of Abitibi River), the RF modem is located between the UHF transceiver and the DC 112 telephone modem.

The UHF transceivers are modified Motorola HT90 portable radios. One transceiver is located between the RF modem and the antenna at the field station, while the second transceiver is located between the antenna and the RF modem at the base station. At the field station the transceiver is powered by a 12-volt supply from the PS35 charging regulator via the solar panel. The transceiver at the base station is powered by a 12-volt battery set-up, which in turn is charged by an AC - DC converter. Each transceiver (field and base station) is connected to an antenna, which transmits UHF signals between the two stations.

3.7 Telephone Modems and Lines

Telephone modems allow the data logger on a remote site to communicate via telephone lines with a computer at the home base. An originate Campbell Scientific DC 112 modem at Abitibi Canyon GS converts asynchronous data from the data logger into synchronous data for transmission over the telephone lines. An answer modem (ie, Hayes Smartmodem 1200) at a distant location (ie. Civil Maintenance Department) converts the synchronous data into synchronous data prior to sending information into the RS-232 port of the computer for storage. The data transmission rate is either 300 or 1200 bits per second.

3.8 Computer and Peripherals

An IBM compatible computer with a RS-232 port, 640K memory and preferably a hard disk, is required to collect and convert the data into a user friendly format. The computer should have a printer and/or plotter to print and plot data. Traditionally programs such as Lotus 123 and Freelance Plus have been used to plot the data.

4.0 INSTALLATION

4.1 Extensometer

A three-point extensometer was installed in the rock mass on the north-east tailrace slope (Figures 1 and 3). The extensometer was placed in a borehole (BH-2) which was drilled at an angle of 60° from the horizontal and in an direction perpendicular to the tailrace channel (ie, north-east). The deepest anchor (#3) was placed in the more stable rock (64 feet) below the fault plane of the rock wedge. The other two anchors (#1 and #2)

were placed at depths of 24.5 feet and 48.0 feet in the rock wedge. This set-up would allow any movement in the rock wedge to be reference back to the deep anchor which is located in the stable rock mass.

The three fibreglass rods of the extensometer had been cut to allow installation of the anchors at the appropriate depths. The extensometer was uncoiled and lowered down the borehole. Each hydraulic anchor was pressurized and seated in the borehole using hydraulic lines and a hydraulic hand pump. Once the anchors were pressurized, the hydraulic lines were sealed at the top to maintain pressure in the system. Grouting was not used for the following reasons: 1) the possibility of inducing pressure to the wedge as a result of the grouting operation, 2) loosing grout through the rock fractures which could result in a poorly installed anchors, 3) sealing the rock fractures which could lead to higher water pressures behind the wedge, and 4) retrieval of the extensomer if required.

The head assembly for the three remote readout linear potentiometers were recessed below ground level to protect them from the harsh environment.

4.2 Inclinometers

Figure 1 is a plan view showing the locations and directions of the inclinometers with respect to the tailrace channel. Two inclinometers, called I100X and I100Y were placed at a depth of 100 feet in a vertical borehole (BH-1A) located near the edge of the eastern slope. Two other inclinometers, called IN4X and IN4Y were placed at a depth of 4 feet in a vertical borehole (BH-1) located slightly further from the edge with respect of BH-1A. The locations are more easily visualized by viewing Figure 3. This figure also shows the fault plane at a depth of 52 feet and dipping approximately 25° north-west. The inclinometers at the 100 foot depth (I100X and I100Y) are the reference points located in the stable rock, while inclinometers IN4X and IN4Y are located in the questionable rock wedge. At each location, one inclinometer measures tilt in the "X" direction while the second inclinometer measures tilt in the "Y" direction. ("X" is perpendicular to "Y"). The locations of the "X" and "Y" directions for both inclinometers are shown in figure 1. The resultant tilt and direction can be calculated from these two inclinometers

The inclinometers were packaged in PVC tubing and the complete system was also installed using lengths of threaded PVC tubing. Upon completion of the installation the PVC tubing was left in the hole. Again grouting was not used for the same reasons as

indicated previously. In addition, it is now possible to replace, repair or calibrate an inclinometer after it has been installed. The tops of the boreholes were sealed using insulating foam, which was then covered with tar to keep the sun's rays from breaking down the foam.

4.3 System Set-Up

The transmission cables from the extensometer and inclinometers all run into an environmental box, which is fastened to the antenna mask at the field location (Figure 4). A second environmental box (lower) houses the batteries. The data logger, regulator, relay switch, RF modem, transceiver and data storage module are also located in these environmental boxes. The solar panel is fastened above the two environmental boxes on the antenna mask and is responsible for providing power to all of the equipment and instruments as well as charging the batteries.

At the base station on the west side of Abitibi River, a second antenna has been fastened to the outside wall of the pump house (Figure 5). Inside of the building, an instrumentation box has been fastened to the wall. This box contains a transceiver, RF modem, telephone modem and a 12-volt battery and power supply (Figure 6). The batteries are continuously charged by an AC to DC voltage converter. This is also the location where the data collection system is hooked up to a telephone line to enable communication with the Toronto Office (Figure 3).

Two radio station licences (No's 446-3329048 and 446-3329050) were obtained from the Minister of Communications in order to operate the two transceivers in accordance with the Radio Communication Act of Canada.

4.4 Data Reduction

Anchors 1 (24.5 ft) and 2 (48 ft) are located in the rock block of interest while anchor 3 (64 ft) is installed in the stable rock below. The assumption is that the bottom anchor will not move and is, therefore, a fixed reference point. Movements in the rock block will be indicated by displacement changes between anchors 1 and 2 and the reference point. Movement in the positive direction indicates block movement towards the river (tension) while movement in the negative direction indicates movement away from the face (compression). Since the extensometer has been placed at an angle of 60° (from

horizontal) into the bedrock, movement in the horizontal direction must be resolved. This can be calculated by using:

$$b = c \cos 60° \quad (1)$$

where b = horizontal movement (inches)
c = hypotenuse movement (inches)
$60°$ = angle of drillhole

The direction of the horizonal movement (X) will be in line with the extensometer installation, which is approximately perpendicular to the slope along the Abitibi River (Figure 1). This means that the horizontal movement is an apparent movement and not necessarily a true movement. The resultant dip direction from the inclinometers can be used to correct the extensometer reading as follows:

$$c = b / \cos A \quad (2)$$

where c = actual movement (inches)
b = apparent movement (inches) from equation (1)
A = angle between extensometer orientation and dip direction obtained from inclinometers (see below)

The inclinometers placed at the 100-foot depth are used as a reference point since they are located well below the rock block. The inclinometers at the four-foot depth are located near the top of the wedge and will respond should the wedge happen to tilt. The readings are converted from voltage to degrees. The positive "Y" direction of one inclinometer is oriented south while the negative "Y" direction is oriented north. The second inclinometer has the negative "X" direction oriented east and the positive "X" direction oriented west.

Since each inclinometer measures a tilt in its own plane, the resultant is obtained by obtaining the actual displacement for each inclinometer in the horizontal plane. This is accomplished by the following:

$$X = d \tan\theta_x \text{ and } Y = d \tan\theta_y \quad (3)$$

where X = horizontal displacement in the x direction (E - W)
Y = horizontal displacement in the y direction (N - S)
d = depth of inclinometer
= 4 feet for the upper inclinometer
= 100 feet for the lower inclinometer
θx = angle of tilt for the x - inclinometer
θy = angle of tilt for the y - inclinometer

The vector resultant of the "x" and "y" displacements in the horizontal plane can then be resolved to obtain the overall tilt direction. The magnitude (a) of the displacement in the resultant direction can be obtained by:

$$a = \sqrt{x^2 + y^2} \quad (4)$$

where x = horizontal displacement in the "x" direction
y = horizontal displacement in the "y" direction

The angle of tilt (A) in the resultant direction is then obtained by:

$$A = \arctan(a/b) \quad (5)$$

where a = displacement in the resultant direction
b = depth of inclinometer
= 4 feet for upper inclinometer
= 100 feet for lower inclinometer

4.5 System Performance

When the remote monitoring system was first placed in operation, the batteries lost their charge due to the cold weather. At the time, the solar panel was tilted backwards and

this caused snow and ice to settle on to it, thereby making it less effective. To rectify the situation, the solar panel was placed in a vertical position. In an effort to conserve energy, relay switches were installed in conjunction with the inclinometers. Instead of providing power constantly to the inclinometers, power now is only provided as before.

The system performed well until June (1990). At this time, the two lower inclinometers provided erroneous readings. The inclinometers were examined and noted to have been shorted out due to the ingress of water. Two spare inclinometers were installed subsequent to waterproofing them in a grease-filled PVC pipe. To date, this repair appears to have been effective in keeping water out of the inclinometers.

4.6 Crack Gauges

Two crack gauges were installed on the concrete wall in the area of the overhead crane on the south tailrace slope (Figure 7). The crack gauges (Figure 8) are designed to allow the measurement of cracks in three directions. The cracks in the concrete coincide with a major fault, which also forms one side of the rock wedge that is being monitored with the extensometer and inclinometers on the north tailrace slope. At present, the two crack gauges are being read manually using a digital micrometer.

5.0 RECOMMENDATIONS

In order to maintain a highly functional and useful monitoring system, the following recommendations are suggested:

1. Data should be reviewed regularly.

2. Questionable performance or data should be reported as soon as possible to the Rock Science Section (Civil Research) so that equipment checks can be performed.

3. The monitoring system at Abitibi Canyon should be checked at least once a year to ensure that the equipment is properly maintained.

4. Any alterations required in the computer program, which collects and analyzes the data from the site (not plotting and printing programs such as Lotus 1-2-3),

should only be undertaken after consultation with the Rock Sciences Section (Civil Research). This is necessary to enable efficient trouble-shooting if required at some time in the future.

5. The three directional crack gauges located on the concrete wall on the west side of the tailrace channel should be read at a minimum of twice annually until further notice.

6.0 CONCLUSION

The Rock Sciences Section (Civil Research) has installed a remote monitoring system at Abitibi Canyon GS to monitor potential movement and tilt in a questionable rock wedge on the east tailrace wall. All data can be retrieved from the site and viewed on a computer (ie, Civil Maintenance Department) in a matter of minutes. This permits the engineer to monitor the behaviour of the rock wedge at all times so that remedial measures can be instigated, at an early stage, if required.

7.0 ACKNOWLEDGEMENTS

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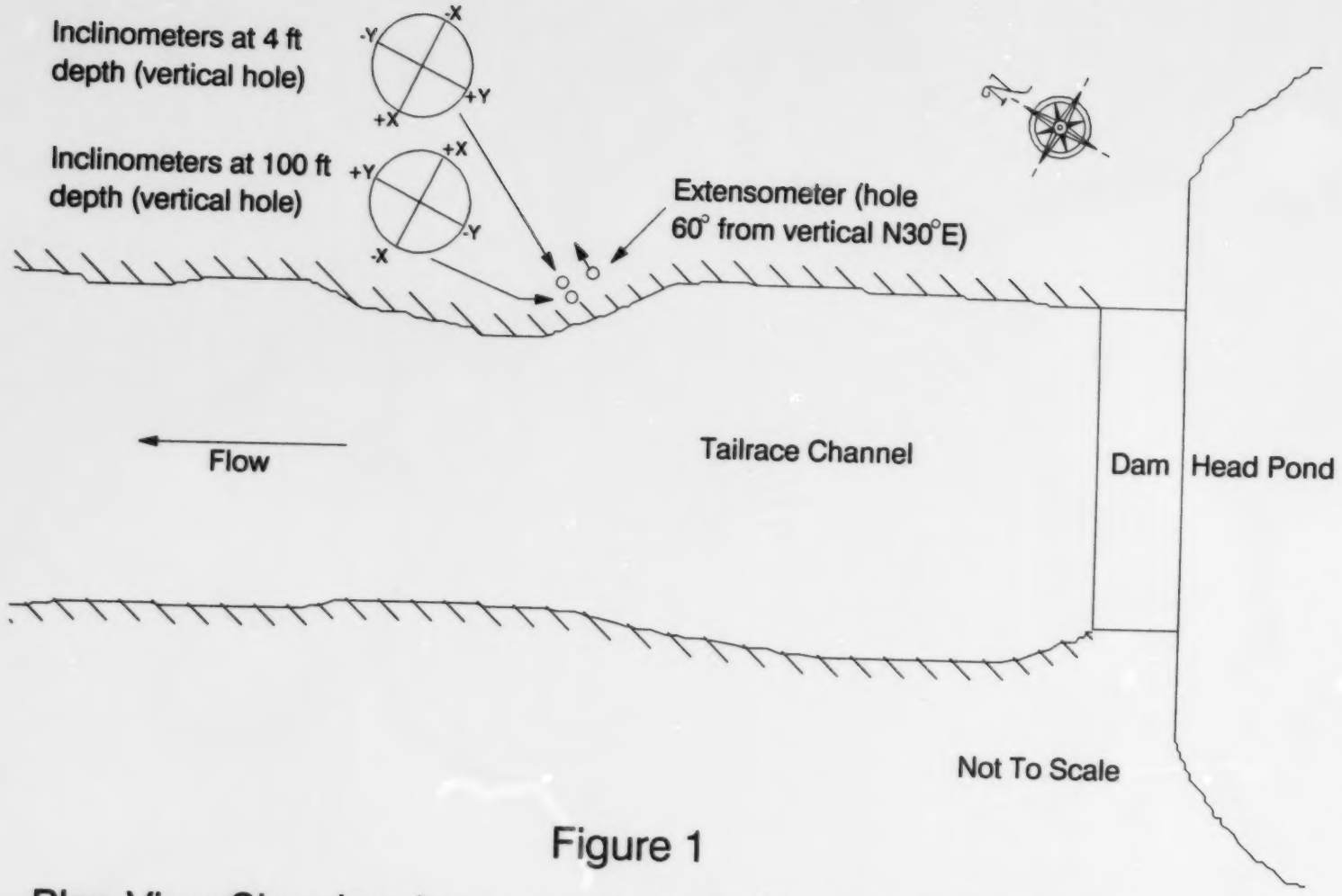

Figure 1

Plan View Showing Approximate Locations And Directions Of Inclinometers and Extensometer With Respect To Tailrace Channel

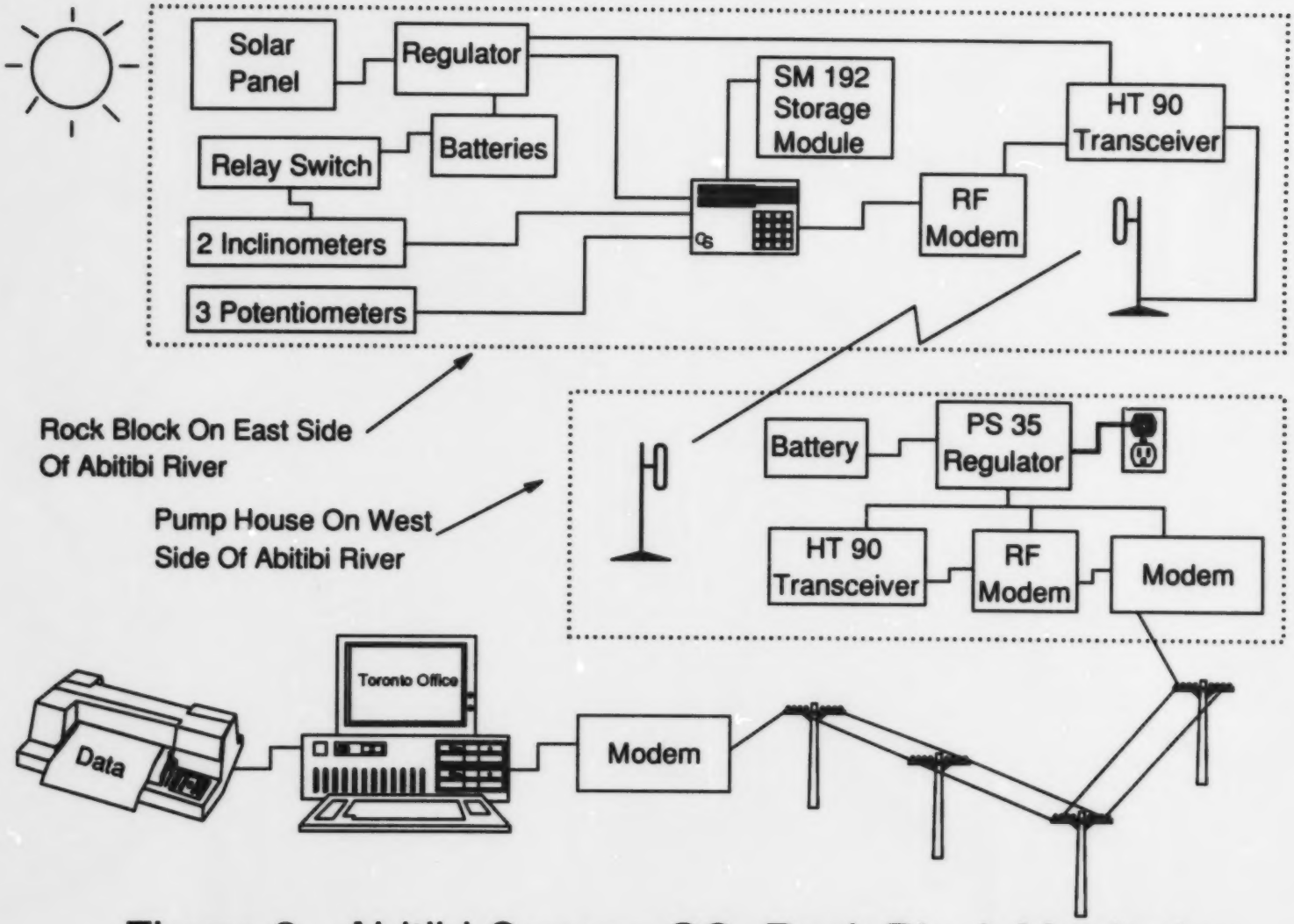

Figure 2 - Abitibi Canyon GS- Rock Block Monitoring

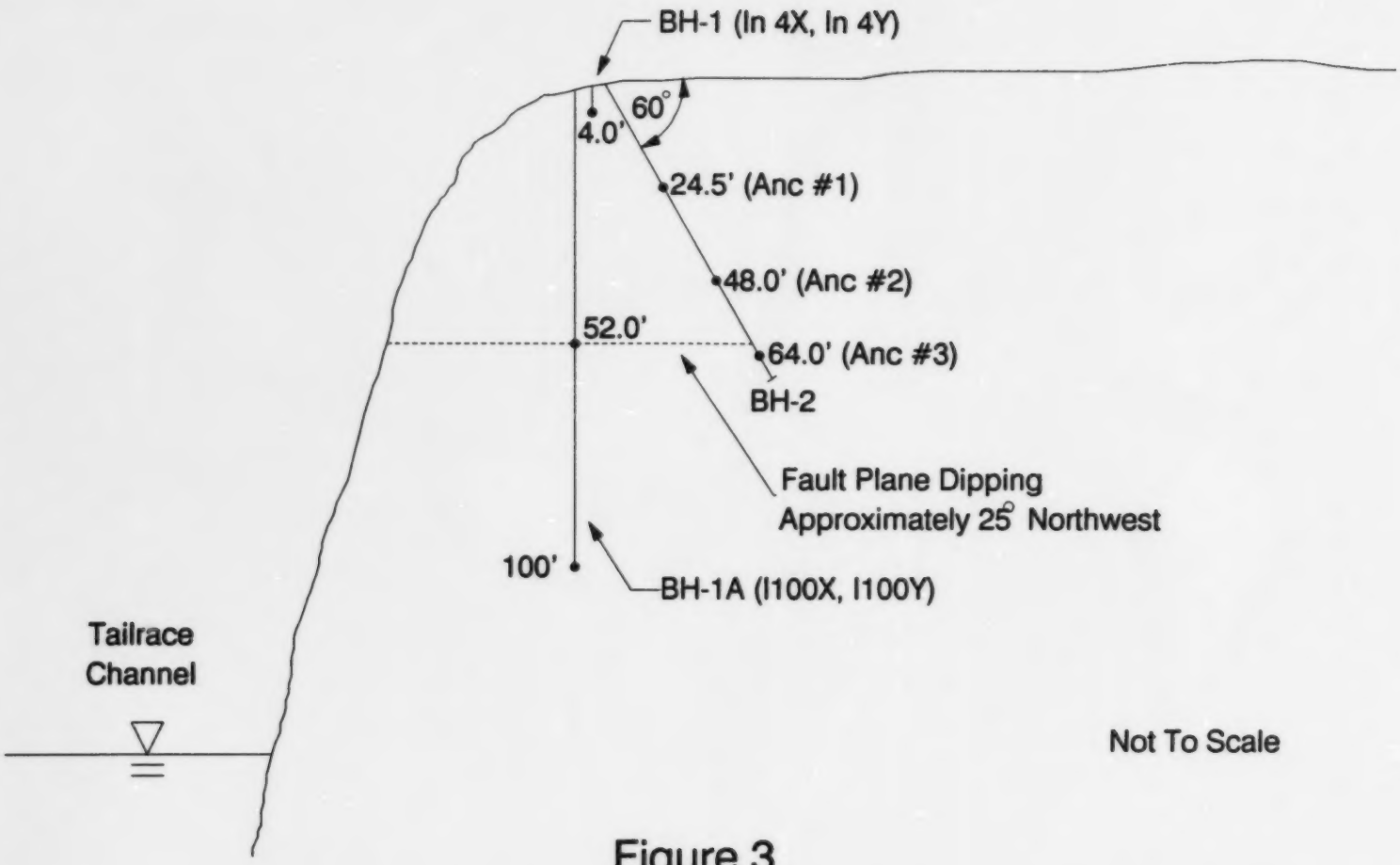

Figure 3

Cross-Section View Looking Downstream and Showing Approximate Locations of Inclinometers and Extensometer Points

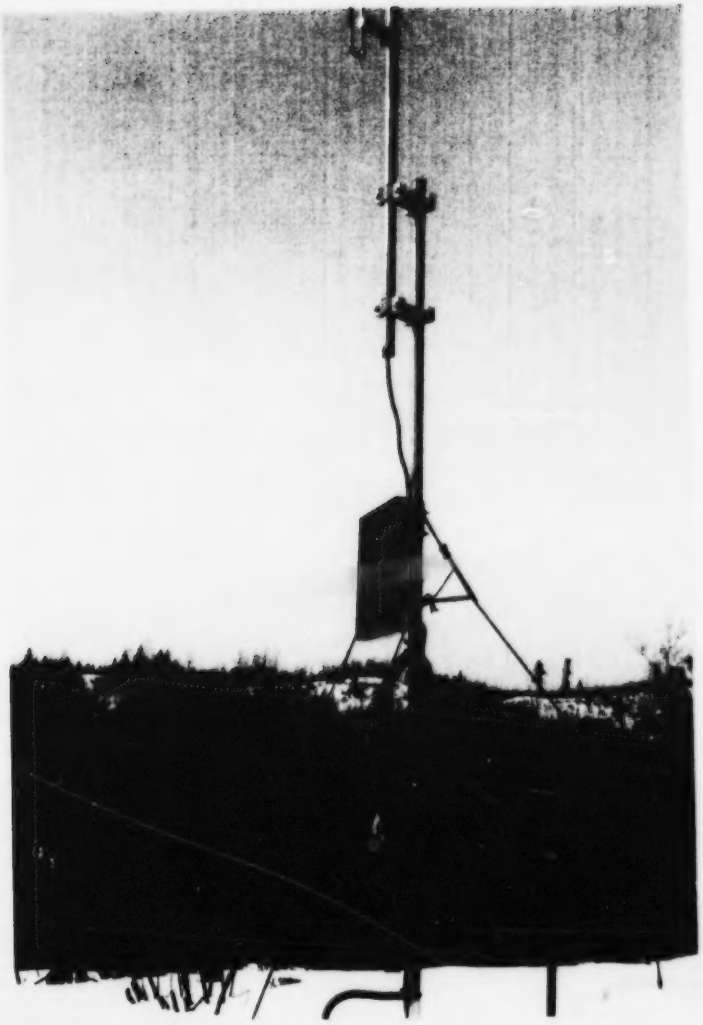

Figure 4: Data Collection Equipment, Solar Panel and Antenna on East side of Abitibi River

Figure 5: Antenna On Pump House On West Side of Abitibi River

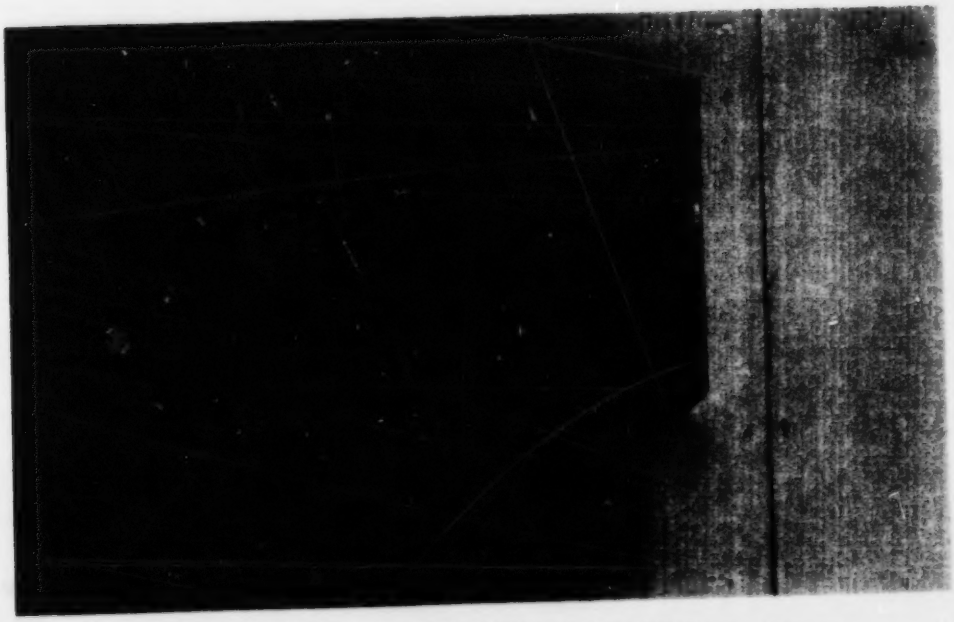

Figure 6: Instrumentation Box Inside Of Pump House

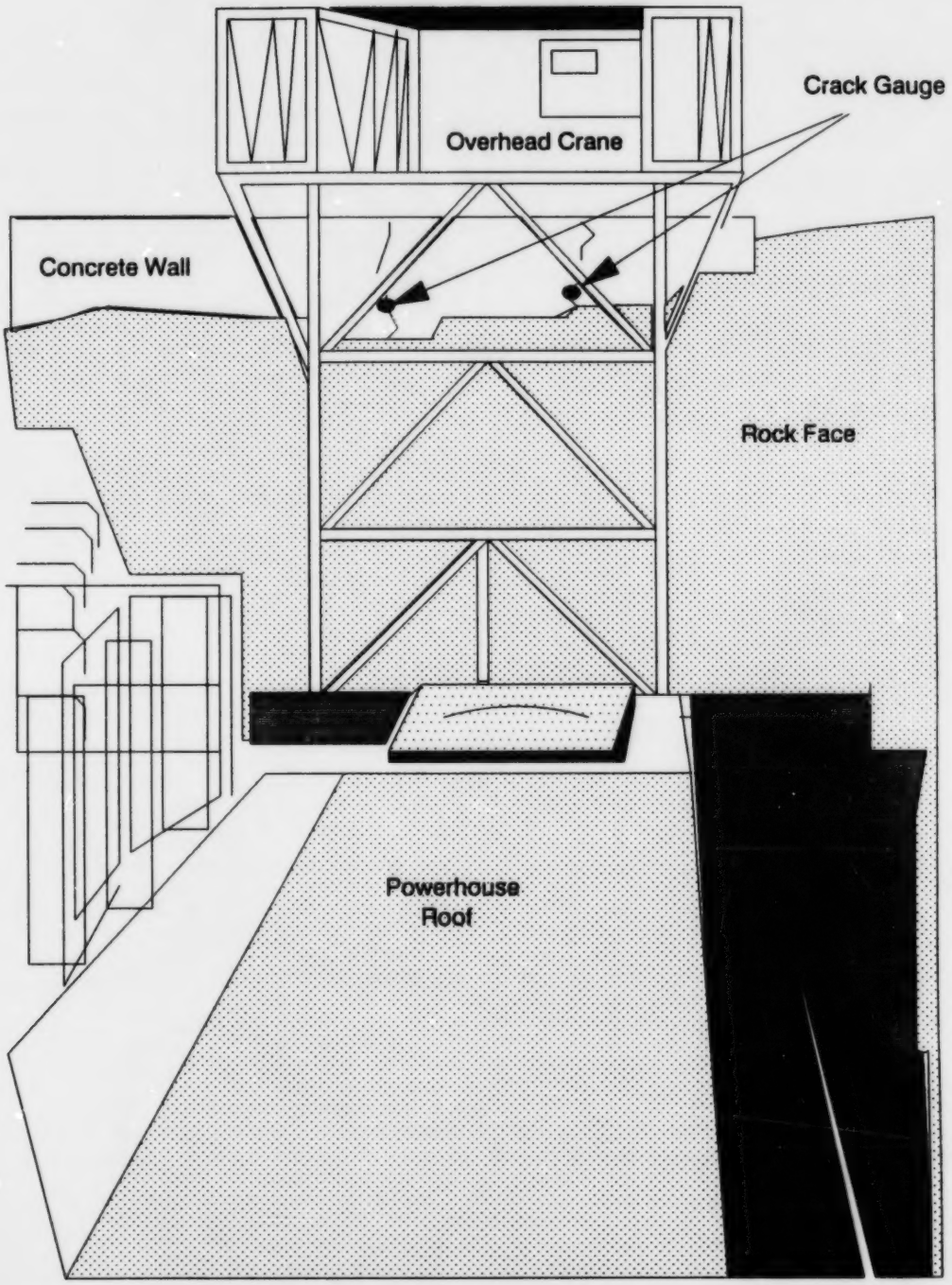

Figure 7
Location of Crack Gauges
Above Powerhouse Roof on West Wall

Figure 8: Crack Gauge Monitoring Crack on West Concrete Wall Above Powerhouse Roof

APPENDIX A:
BOREHOLE DRILL LOGS

DRILL LOG - ABITIBI CANYON GS

Date: August 22, 1989 Borehole: 1
Dip: 90° Hole Type: NQ-3

Depth (ft)	Description
0.0 to 5.1	- Overburden - boulders up to ~18" diameter - Peat, sand, pebbles, etc (none collected)
5.1 to 9.6	- Bedrock - highly fractured, medium grained metavolcanic migmatite. - Minor quartz veinlets - Oxidation and fractures along veinlets - Very highly fractured from 6.4 to 7.6 ft
9.6 to 11.9	- As above - Very highly fractured - No visible sulphides
11.9 to 12.9	- As above - Much less fracturing
12.9 to 16.1	- As above with less fracturing - Fracturing still occurs along quartz veinlets, but oxidation to a lesser degree - Quartz veinlets present, but separated from rock along fracture planes - Quartz appears in veins approximately 0.5 in thick at 15.9 ft - No fracture associated with quartz
16.1 to 21.1	- Rock as above - Much less fracturing and oxidation - Fractures that occur do so along quartz veinlets - Quartz veinlets have come away from the rock

DRILL LOG - ABITIBI CANYON GS

Date: August 22, 1989 (Cont'd) Borehole: 1
Dip: 90° Hole Type: NQ-3

Depth (ft)	Description
	- Quartz has a greenish hue epidote - Fracture and quartz oxidation to a much lower extent than before - longest piece - approx. 15 inches
21.1 to 26.2	- Rock as before - Quartz veinlets - Slight oxidation visible
26.15 to 26.3	- Lost core
26.3 to 30.7	- As above
30.7 to 31.4	- Epidote alteration veinlets
32.8	- Lost water - regained shortly after
31.4 to 36.4	- As above - Qtz and epidote
36.4 to 40.5	- As above - 39.3 to 39.1 - large quartz vein with epidote - Grain size slightly decreasing - Fracturing and oxidation much less evident
40.5 to 41.5	- As above - Variation in grain size
41.5 to 46.5	- As above - Much less fracturing
46.5 to 55.9	- Highly siliceous - Quartz veinlets from 0.25 to 0.7 inch - Quartz filled cavities and vugs

DRILL LOG - ABITIBI CANYON GS

Date: August 22, 1989 (Cont'd) Borehole: 1
Dip: 90° Hole Type: NQ-3

Depth (ft)	Description
	- Dissemination very visible on surface as well as fracture surfaces - Yellowish return water from 51.5 to 52.1 ft - Highly siliceous from 51.5 to 52.3 and 54.9 to 55.6 ft
55.9 to 60.8	- As above - Siliceous & quartz veinlets - the angle with respect to vertical are increasing
60.8 to 61.1	- As above
61.1 to 65.4	- As above - Minor fracturing - Quartz zone from 62.1 to 62.9 ft
66.0	- Bottom of hole - core jammed in innertube.

DRILL LOG - ABITIBI CANYON GS

Date: August 30, 1989 Borehole: 1A

Dip: 90° Hole Type: NQ-3

Depth (ft)	Description
0.0 to 5.0	- Very weathered metavolcanic migmatite - Poor recovery
5.0 to 10.0	- As above - Weathering with quartz veinlets
10.0 to 15.0	- As above and less weathering - Quartz veinlets - Passes through 3 inch thick light grey feldspar / quartz layer - blocked tube at 15.0 ft
15.0 to 20.0	- As above - Highly fractured at 17.5 ft.
20.0 to 25.0	- As above - Interspersed zones of weathering associated with quartz filled veins
25.0 to 30.0	- As above - Less fracturing at 26.5 ft - Increased fracturing at 29.0 ft
30.0 to 35.0	- As above - Lost 1 ft of core from 34.0 to 35.0 ft (re-drilled and retrieved)
35.0 to 40.0	- As above - Quartz filled veins - Composition of rock changing (smaller fragments)

DRILL LOG - ABITIBI CANYON GS

Date: August 30, 1989 (Cont'd) Borehole: 1A

Dip: 90° Hole Type: NQ-3

Depth (ft)	Description
40.0 to 45.0	- As above - More highly broken - Contains quartz veinlets
45.0 - 50.0	- As above - Less highly broken - Weathered quartz veins
50.0 to 51.5	- As above - Very siliceous - Greenish (epidote)
51.5 to 52.5	- As above, but extremely weathered with epidote - Yellowish return water - Broken rock returned
52.5 to 56.0	- As above, but greenish - Numerous quartz veinlets - Presence of garnets
56.0 - 60.5	- As above, but greenish - Numerous quartz veinlets - Presence of garnets
60.5 to 65.0	- As above - Veins of quartz and orthoclase present
65.0 to 70.0	- As above, but greenish - Veins of quartz and orthoclase present
70.0 to 75.0	- As above - Presence of epidote and siliceous veining

DRILL LOG - ABITIBI CANYON GS

Date: August 30, 1989 (Cont'd) Borehole: 1A

Dip: 90° Hole Type: NQ-3

Depth (ft)	Description
75.0 to 76.5	- As above
76.5 to 80.0	- As above with zones of quartz and feldspar
80.0 to 85.0	- As above with a series of feldspar and calcite veins
85.0 to 95.0	- As above with quartz veins
95.0 to 100.0	- As above with quartz / feldspar at 100.0 ft
100.0	- End of hole

DRILL LOG - ABITIBI CANYON GS

Date: September 4, 1989 Borehole: 2
Dip: 60° Hole Type: NQ-3

Depth (ft)	Description
0.0 to 5.0	- Overburden
5.0 to 10.0	- Metavolcanic migmatite - Highly weathered along quartz veins
10.0 to 15.0	- As above, blocked at 12.0 ft - Some fragmentation noted - Minor quartz veinlets
15.0 to 18.6	- As above - Minor quartz veinlets
18.6 to 23.6	- As above - Highly weathered seam at 19.0 ft - Minor quartz veins
23.6 to 28.6	- As above - Minor quartz veinlets - Orthoclase vein encountered - Poor recovery from 28.1 to 28.5 ft
28.5 to 33.6	- As above (slightly green)
33.6 to 38.6	- As above - Increase in quartz veinlets
38.6 to 43.0	- As above - Intersected 1/4 in epidote seam in zone from 39.6 to 41.6

DRILL LOG - ABITIBI CANYON GS

Date: September 4, 1989 (Cont'd) Borehole: 2
Dip: 60° Hole Type: NQ-3

Depth (ft)	Description
43.0 to 48.0	- As above
48.0 to 53.0	- As above - Rock more broken, blocky - Quartz veins
53.0 to 58.0	- As above - Weathering along quartz veins
58.0 to 59.0	- As above, but broken, blocky
59.0 to 60.0	- Highly fractured - Fractures infilled with silica
60.0 to 60.6	- Alteration zone - brownish, highly weathered
60.6 to 62.6	- As above with large quartz veins present
62.6 to 66.0	- As above with quartz and feldspar - Extremely hard, very slow drilling
66.0	- End of hole